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DEVELOPMENT OF SOVIET GEOPHYSICS

V. V. Shuleykin

/Figures are appended./

I.

The development of Soviet geophysics is characterized by two basic features: first, by the birth and development of new branches of geophysics in the USSR; and second, by original studies of unparalleled scope.

The civil war had scarcely ended when squads of geodesists, hydrographers, magnetologists, and gravimetrists went out into the field. The Special Commission on the Study of the Kursk Magnetic Anomaly was created by Lenin's order.

The magnetic anomaly in the Kursk and Khar'kov regions was discovered in the XIX Century, and Professor Leyst of Moscow did much valuable work on accurate determination of elements of the geomagnetic field, except that he did not determine the geographical coordinates of the points which he studied. As a result, the minute accuracy of the magnetic measurements was worthless, but the Germans, who by some devious methods had obtained these maps after Professor Leyst died, tried in vain to entice the Soviet government into buying these maps. Academician P. P. Lazarev rightly proposed that rather than purchase these doubtful and incomplete documents, a new study of the vast magnetic anomaly should be made using expedition methods similar to those used for marine hydrographic studies. These expedition methods made possible both magnetic measurements and determination of geographical coordinates with uniform high accuracy. Excellent maps were constructed of the distribution of the main elements of the geomagnetic field in the region from approximately 50° to 52.5° N latitude and from 33.5° to 38.5° E longitude. The underground ranges of magnetite rocks stood out clearly on these maps.

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Extensive studies made by field workers required completely new methods for laboratory studies of core samples. They gave rise to interesting new methods for the interpretation of maps, i.e., for establishing the connection between the external fields shown on the maps and the position and magnetic properties of the hidden rocks causing the anomaly.

The magnetic observations directed by Lazarev and N. K. Shodro were closely connected with geological studies organized by I. P. Gubkin and gravimetric studies organized by A. A. Mikhaylov. Clear gravitational anomalies were discovered in the places where magnetic anomalies were observed. The seismologists P. M. Nikiforov, M. I. Polikarpov, and G. A. Gamburtsev also conducted works in this region. At the same time, A. I. Zaborskiy began his extensive independent studies. The voluminous data obtained in the region of the Kursk magnetic anomaly by representatives of the most diverse branches of science permitted A. D. Arkhangel'skiy to make broad generalizations on the relationship between geological structure and gravitational anomalies in the European USSR.

By refuting the primitive notions of some West European researchers who were transfixed by the isostasy hypothesis, Arkhangel'skiy did much to develop geophysical methods of studying the structure of the earth's crust. In particular, the interesting contemporary studies of slow oscillations of the earth's crust, leading to the formation of highlands and recessions of continents and seas, are based upon his work. While on this subject, it is interesting to note that V. V. Belousov and his coworkers have compared powerful deformations of strata in nature with similar effects in plastic laboratory models.

The extensive development of field studies under the direction of the Special Commission on the Study of the Kursk Magnetic Anomaly brought forth many new instruments. One of these was Gamburtsev's field seismograph, which subsequently was used in numerous seismological mineral explorations. New experimental techniques made it possible to re-equip the net of seismological stations, which was founded by B. B. Golitsyn and subsequently developed by Nikiforov, V. F. Bonchkovskiy, and Ye. F. Savarenskiy. Bonchkovskiy proved the connection of microseisms with cyclones and storms.

L. V. Sorokin made interesting, unique studies on gravimetry in the sea from a submarine. The results of these works confirmed Arkhangel'skiy's hypotheses on the tectonic processes causing Crimean earthquakes.

The magnetic survey made by Soviet researchers in the Kursk, Khar'kov, and Voronezh regions was subsequently extended to the whole country. Since 1931, a great deal of work has been done on the construction of a regional magnetic map of the USSR. These works were initiated by a group from the Main Geophysical Observatory, and from this group there was subsequently formed an independent Institute of Terrestrial Magnetism, directed by N. V. Pushkov.

In connection with the study of earth currents, new applied branches of science developed in an allied field, i.e., electrical methods of prospecting for mineral resources. While doing field work in electrical prospecting, A. G. Ivanov stumbled onto an extremely interesting new effect, the so-called seismoelectric effect of the second type.

II.

The great historical date of 1917 marked the beginning of systematic scientific study in the physics of river-bed flow in the field of contemporary hydrology. A group of important workers of the Administration of Inland Waterways and workers of the Division of Land Improvement, together with geographers, geophysicists, hydrochemists, and others, organized the State Hydrological Institute under the general direction of the Academy of Sciences.

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One of the most important problems solved by the workers of the State Hydrological Institute, mainly M. A. Velikanov, Corresponding Member, Academy of Sciences USSR; V. M. Makkayeyev, N. M. Bernatskiy, and A. A. Satkevich, was that of the turbulence of river currents. Velikanov also created a new theory of the movement of suspended alluvia based on mathematical data.

Nonstationary movement of water in canals was studied by Academician S. A. Khristianovich, who succeeded in integrating for the first time the equations of nonstationary motion of a fluid. The extremely complex form of the exact solution given by Khristianovich hindered practical use f the method until V. V. Vedernikov, Arkhangel'skiy, and G. P. Kalinin derived very simple approximate solutions based on Khristianovich's work. Velikanov and his coworkers also did extensive work on the influence of rivers on the formation and changes of the bed. S. I. Rybkin found important morphometric dependencies for the lowland rivers which are characteristic of many regions of the Soviet Union. The mechanism of the destructive mud streams of Middle Asia and the Transcaucasus was studied by A. N. Konovalov and D. L. Sokolovskiy.

The Soviet Union initiated research on the determination of river runoff. Organization of scientific research runoff stations was proposed by Velikanov. D. I. Kocherin, B. D. Zaykov, and others obtained valuable data on runoff norms, and Zaykov drew up not only an excellent map of the distribution of runoff moduli for the Soviet Union, but also the first map of runoff distribution for all of Europe.

The mechanism of ground water movement was also studied for the first time by Soviet scientists, beginning with the first works of N. N. Pavlovskiy and ending with the most recent studies by P. Ya. Kochina, Corresponding Member Academy of Sciences USSR.

Works of river hydrophysicists on the origin of bottom ice were of great theoretical and practical importance, especially those of V. Ya. Al'tberg, a pupil of the great physicist P. N. Lebedev. Subsequently, V. V. Piotrovich and S. Ya. Vartazarov discovered that the so-called bottom ice could also form in the cross section of river flow, although it forms primarily on the bottom and on various objects (anchors, etc.) submerged in the river.

III.

On 16 March 1921, Lenin published a decree which began with the words: "For comprehensive and planned study of the northern seas, their islands, and shores, which are of great importance to the state at this time, the Plovmornin (Floating Marine Scientific Institute), affiliated with the People's Commissariat of Education, is established. ..."

The institute was not named accidentally; it was actually a floating institute. All its personnel were closely associated with the expeditionary ship Persey which belonged to the institute and made long trips into the Barents, Greenland, White, and Kara seas. Without exaggeration, we can state that all our marine research institutes grew in one way or another from this remarkable institute; in all of them, the administrative work is carried out either by founders of the Plovmornin or by those educated on its expeditions. The first Soviet studies on the physics of the sea began in these expeditions, either on board the Persey itself or on board hydrographic and transport vessels of other offices with which the institute cooperated.

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Black Sea Hydrophysical Station

The expeditionary works, however, were still intermittent in nature. Drawing from the experience of biologists, who had long recognized the need for permanent marine biological stations, Soviet hydrophysicists began permanent year-round work on the physics of the sea at the Black Sea Hydrophysical Station in the village of Katsiveli near Simeyz. This station was founded in 1929 by the author and later became part of the Academy of Sciences.

As far as we know, except for the Moscow laboratory, the Black Sea Hydrophysical Station is the only research institution in the world specializing on the physics of the sea.

Work on the molecular physics of the sea at the station is also directly connected with studies of sea waves. By means of a simple and convenient instrument based on the Gay-Lussac principle, we succeeded in measuring the surface tension directly in the sea, i.e., by pulling from the sea surface the glass bottom of a cone which is suspended from a spring dynamometer. It was then discovered that the surface tension drops to 50, 34, or even to 22 dynes per cm on those sea sections where there are traces of some surface-active substances in contrast to the 73 dynes per cm associated with the pure sea surface. Much work has been done on the problem of using wave energy for power units. However, the numerous works of French authors did not lead to any effective method for using wave energy, since the moving parts of their wave machines rapidly wore out under the action of storm waves. In the USSR, Ye. S. Avtonomov proposed an interesting design which contains no moving parts and thus does not suffer from the destructive action of storm waves. Avtonomov tested his unit first in the laboratories of the Black Sea Hydrophysical Station and later on the seashore. His unit makes use of the hydraulic ram effect; the waves crash into wedge-shaped sections of a quay and produce high crests; the water which is lifted up passes into a collection trough and can then be dropped through any turbine which is designed for this head. In some cases, Avtonomov obtained wave crests whose height was ten times the wave amplitude, i.e., five times the height from the trough to the crest of the wave.

At the Black Sea Hydrophysical Station, interest has heightened recently in the field of optics of the sea, with which Soviet hydrophysicists began to work while still on the hydrographic ship Pakhtusov in 1922 and on the expedition ship Persey in 1924. This branch of geophysics was established simultaneously in the USSR and India. In 1921, independently of each other, V. V. Shuleykin in Yalta and Ch. V. Raman in Calcutta proposed a theory on the origin of the color of the sea. Shuleykin derived the spectral formula for the light coming from the depths of the sea in its most general form, while Raman applied this to the partial case of purely molecular scattering, which holds for the crystal-clear waters of the Bay of Bengal. In addition, Shuleykin's work permitted calculation of the amount of light reflected from the surface of a calm sea and from a wave surface for various angles of sight and various wave curvatures. The role of the size of particles scattering the light was determined theoretically and experimentally. In contrast to the opinion of Raman and his Indian school, the role of large scattering particles, e.g., air bubbles and suspended particles in sea water, is very important and sometimes even decisive. The theory of multiple scattering of light by these particles which the Soviet group developed showed that in the region of extreme blue and ultraviolet, where the solar rays are not absorbed but only scattered by water, sharp deviations from Buch's law should be expected, because of scattering of higher orders, light here should be attenuated much less rapidly and in its penetration into the depths of the sea, it should be attenuated, according to the hyperbolic law established by Shuleykin.

Experiments with artificial media which strongly scatter but do not absorb light were made by V. A. Timofeyeva at the station and confirmed Shuleykin's theory. The theory was again confirmed by an effect discovered by Beebe in his bathysphere (unnoticed by physicists until recently); namely, that at depths of around 250 m the external illumination becomes blue and then even violet. It can be shown that for attenuation of light according to Buch's law within the entire visible spectrum, the illumination at such depths would be invisible to the eye, and if visible, would be green. The colors observed by Beebe can be explained only by slow attenuation of light (according to the hyperbolic law) in the blue and violet regions, in which, in contrast to the remaining regions of the visible spectrum, there is no absorption of light.

A new original chapter in the history of the physics of the sea was written by the investigations of A T Mironov. He discovered electrical currents of considerable density in the waters of the Barents Sea. Skeptics from the Geological Prospecting Administration equipped an expedition to check his measurements; when they lowered electrodes connected to a sensitive galvanometer into the sea, the galvanometer quickly burned out. Mironov is studying these sea currents systematically at the station, and has now succeeded in proving the complete correlation between intensification of currents and magnetic storms (Figure 1) and the behavior of sunspots, flare-ups, and floccules. Mironov currents undoubtedly owe their origin to solar corpuscular radiation, and therefore their density is greatest in polar seas. They have nothing in common with Faraday currents, which originate in the movement of air masses in the geomagnetic field.

Other Scientific Institutions

In addition to the Black Sea Hydrophysical Station, other scientific institutions which do not specialize in this branch of geophysics are conducting investigations on the physics of the sea. For example, in the field just discussed, namely, optics of the sea, much has been done by A. A. Gershun and N. A. Boldyrev, scientific workers of the State Optical Institute, and also by Professor Vs. A. Berezkin (deceased) of the Naval Academy.

Many USSR research institutes have done some work in other branches of the physics of the sea. For example, in the Geophysical Institute, Academy of Sciences USSR, L. N. Sretenskiy, Corresponding Member, Academy of Sciences USSR, introduced new features into the theory of tides in the polar basin. Berezkin also worked on this problem with his students in the Naval Academy. Academician A. I. Nekrasov, L. N. Sretenskiy, and K. K. Fedyayevskiy also did important work on the theory of waves. In expeditions of the State Oceanographic Institute, A. M. Gusev developed a theory of drift and yawing of a ship under the action of the wind. In the Institute of Oceanology, Academy of Sciences USSR, V. B. Shtokman made a series of studies on the theory of ocean currents, in the equatorial region in particular; he also clarified the theory of turbulent mixing in the ocean and its role in the spread of foreign waters which are introduced into the main water masses of any oceanic region.

Interesting studies on the acoustics of the sea have been made in the Acoustics Laboratory of the Physical Institute, Academy of Sciences USSR, under the direction of N. N. Andreyev, Corresponding Member, Academy of Sciences USSR, and L. S. Sukharevskiy.

IV.

Climatology

Climatology has been put on a firm material basis only in the last 30 years, and primarily in the Institute of Climatology of the Main Geophysical Observatory. The results of the reorganization of work were immediately apparent;

a whole series of monographs on the climatology of the USSR were produced by Ye. F. Ivanova, O. A. Drozdov, A. A. Kaminskiy, V. N. Korotkevich, Ye. S. Rubinshteyn, and others.

Many studies on the climate of the Arctic have been made by V. Yu. Vize, Corresponding Member, Academy of Sciences USSR, beginning with his first expedition with G. Ya. Sedov to Novaya Zemlya and ending with his most recent works. The Moscow climatologists Ye. Ye. Fedorov, Corresponding Member, Academy of Sciences USSR, and B. P. Alisov have also made their contribution to this science.

The first works on the study of weather regularities also originated in the USSR. The most outstanding regularities were first observed by B. P. Mul'tanovskiy, who discovered that weather changes occur with a certain "natural period" and cover a certain "natural synoptic region." By collecting a great number of synoptic maps, Mul'tanovskiy constructed the so-called composite weather maps, which enabled him to establish a definite series of typical sequences in weather changes. Mul'tanovskiy did not attempt to analyze the physicomathematical bases of these regularities and thereby drew criticism which continues to this day. Nevertheless, he developed a long-range forecasting procedure which is now successfully used by several of his pupils, including S. T. Pagava, N. A. Duletova, A. S. Rozhdestvenskaya, A. I. Askinaziya, and N. V. Bulinskaya. Despite its purely empirical basis, Mul'tanovskiy's method remains the only one at present which permits us to predict long in advance the general weather picture in a certain season. Of course, the present long-range forecasts are still very rough and imperfect, but in spite of their inadequacies they have produced some remarkable results. For example, in April 1941, a long-range forecast bulletin was published in which it was announced that snow should be expected during the first days of June in Moscow and later in Leningrad. As predicted, snow fell on 2 June 1941 in the outskirts of Moscow, and on 8 June there was almost a snowstorm in Leningrad. In the summer of the same year, the forecasters announced that ice should be expected in the northern rivers of the European USSR at the beginning of the second 10 days of November; actually, the Severnaya Dvina in Arkhangel'sk froze on 11 - 12 November. At present, a great research institute, the Central Forecasting Institute, directed by D. A. Drogaytsev, is working to improve the various forecasting methods.

The mathematical trend in the work of the Main Geophysical Observatory was established by three outstanding scientists, A. A. Fridman, L. V. Keller, and N. Ye. Kochin. Fridman, in his short life (died in 1937), introduced so many fruitful new ideas into dynamic meteorology that the entire Soviet school of dynamic meteorology is still developing these ideas. The classical studies by Helmholtz and Margules preceding Fridman's studies were somewhat unwieldy, and, therefore, the meaning of the frictional forces which play a decisive role in the layer of air next to earth was not clear. Fridman and Keller established a completely new trend by their study of turbulent viscosity of air; they created a statistical theory of turbulence. They proposed that the structure of turbulent flow be investigated in connection with the characteristics of this flow, i.e., its velocity, pressure, and temperature. This suggestion has now produced very important results in the works of Academician A. N. Kolmogorov, I. A. Kibel', Corresponding Member, Academy of Sciences USSR; M. D. Millionshchikov, A. M. Obukhov, and M. Ye. Shvets. Kolmogorov and Obukhov, in particular, thoroughly developed the science of the scale of turbulence, i.e., of the so-called local structure of turbulence. Their mathematical contributions were confirmed completely in both observations on atmospheric phenomena and special experiments on the behavior of acoustic waves propagated in a turbulent atmosphere (V. A. Krasil'nikov's experiments). Kibel' and Shvets, using the same ideas, clarified the role of turbulence under the thermal conditions of the atmosphere and confirmed the validity of the theory by studying the diurnal behavior of air temperature at various heights.

A descriptive picture of the general circulation of the atmosphere was first given by Academician N. Ye. Kochin's differential equations. He analyzed the relative weight of the various terms in the cumbersome hydrodynamic equations when written in their general and complete form and, by introducing some simplifications, reduced these equations to a form useful for geophysical studies. Together with Gel'bke, A. A. Dorodnitsyn, and other students of his, Kochin gave the first approximate solution of his equations, obtaining as a result all the basic characteristics of the general circulation of the atmosphere. The Kochin equations still conceal their greatest potentialities. In all countries, meteorologists are trying to obtain more and more accurate solutions for them. These equations will undoubtedly yield many more remarkable and perhaps unexpected results when mathematical techniques are improved.

One might ask the following question: If the simplified equations of hydromechanics permit us to cover the entire general circulation system, could we not apply them together with the heat transfer equations to a certain small area to predict time variations in the different meteorological elements?

Kibel' showed that this problem could be solved. By means of a simplification of the equations of hydromechanics and the heat transfer equations, with a reliable evaluation of the discarded terms, he predicted the weather 24 to 36 hours in advance from the weather at the given time for the given location. Improvement of the method requires accurate determination of the boundary conditions, and wide introduction of it into practice requires education and training of the personnel to perform the calculations. Since this is merely a technical problem, the task of short-range forecasting may be considered solved in principle. Of course, we must make one exception, namely, the Kibel' method cannot take into account exceptional phenomena which develop in the atmosphere, such as hurricanes, tornadoes, winters of the 1940 type, etc.

The works of mathematicians on dynamic meteorology both in the Soviet Union and abroad have not, up to the present, taken into consideration the influence of the underlying surface on atmospheric phenomena. Of the mathematicians, only Ye. N. Blinova has attempted to consider this effect. In her doctor's dissertation, Blinova obtained very interesting results on the distribution of air temperature and pressure over oceans and continents. Even in this work, however, the problem was attacked only formally; no consideration was given at all to the actual physical effects which characterize climate and weather on continents and oceans

A quite different approach to the theory of climate and weather has been attempted by those geophysicists who have made their primary goal the discovery of the physical bases of climate and weather. First of all, it was proven by the works of the Black Sea Hydrophysical Station that climate can be considered as a characteristic of the regime of certain unique "heat machines" in the atmosphere and ocean. There are two types of heat machines operating between heaters and coolers. In the first type, the heaters are invariably the tropical belts of the earth while the coolers are the polar caps and the belts around the poles. In the second type, the heaters are the oceans and seas and the coolers are the continents in the winter; in summer, the heaters and coolers of heat machines of the second type exchange places; i.e., the oceans become coolers and the continents become heaters.

In his first studies of this problem, Shuleykin calculated the thermal currents intruding in winter from the oceans and even from small inland seas and the thermal currents which travel in the opposite direction in summer. In the USSR and other countries with a moderate climate, the winter currents are very sharply defined, while the summer currents are quite weak. The field of these thermal currents which penetrate the lower tropospheric layer (approximately 2 km high in the middle latitudes) is characterized by climatological maps of temperature isanomalies. At each point of the field, the thermal current may be considered as proportional to the isanomaly gradient multiplied by

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some arbitrary heat conductivity coefficient which can easily be determined theoretically. Some heat is lost in transit from the ocean to the depths of continents, but part of it gives additional heat to the atmosphere in the corresponding regions, entering into the heat balance cycle of the atmosphere and finally being radiated into interplanetary space.

The amount of supplementary heat coming from an ocean and also coming from the south along the meridian was calculated theoretically for the Leningrad region and agreed completely with a direct determination by Trolle of elements of the heat balance in Pavlovsk (Slutsk). The theory also agreed well with direct measurements in other respects. The theory of thermal currents in the atmosphere coming from oceans to continents easily explains the origin of the well known cold belt in the Yakutsk SSR and even permits us to determine approximately its geographical position; this region is characterized by a minimum of heat entering from the Atlantic, Pacific, and North Arctic oceans. This region is almost ideally continental; the air temperature there is approximately that which would be observed everywhere at this latitude if there were no oceans on the earth.

In later work at the Black Sea Hydrophysical Station, Shuleykin, A. M. Gusev, and Ye. V. Osmolovskaya showed that the heat entering continents from oceans and inland seas is transported by monsoon air currents; in the lower layer, about 500 m high, in winter cold air flows from continents to oceans, while in the layer extending 1,500 m above the lower layer, currents of considerably warmer air flow from oceans to continents. Heat transfer in the vertical direction is accomplished by turbulent mixing of the air masses. Even now, some meteorologists still doubt whether there actually exist in the upper layer air countercurrents which are directed from the ocean to the continent in winter. These unfounded suspicions can easily be allayed by looking at maps of climatological isallobars; the enormous increase in the amount of air over the continents (especially over Asia and Europe) in winter, in comparison with summer, is caused by these monsoon countercurrents (antimonsoons), the flow of which in autumn exceeds the flow of air currents into the 0-500-m layer. In spring, on the other hand, the flow of currents into the lower monsoon belt predominates and causes a return of the supplementary air masses from the continent to the world ocean.

This movement of the supplementary masses disturbs the position of the earth's axis of inertia and causes forced nutation of the earth's axis of rotation. N. L. Byzova quantitatively confirmed this explanation of the shifts of the poles, which have been so carefully studied by astronomers (especially by A. Ya. Orlov). She proved that the increased amplitude of pole movements, which is observed in certain years, is caused by resonance between the so-called Chandler period of free nutation and a period which might be called the geophysical year, i.e., the time interval between the air temperature minimums of two successive winters.

Workers of the Black Sea Hydrophysical Station have established an analytical dependency between the size of a sea (of simplified circular form) and elements of its heat balance, on the one hand, and the elements of the monsoon field produced over it and over the surrounding continent, on the other. They discovered the distribution of air temperatures over the sea and over the continent, as well as the distribution of velocities and the position of the current lines. The theoretically calculated values agreed well with the results of direct measurements. The connection between the form of a shore line different from a circle and the intensity of a monsoon field was also established. A quantitative explanation was given for the genesis of hurricane storms opposite such sharp-pointed formations as Cape Horn, the Cape of Good Hope, Kanin Nos, Cape Zhelaniye on Novaya Zemlya, and Cape Farewell. This, in general, is the trend of Soviet work on the physicomathematical theory of climate.

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If climate, then, is the characteristic of the regime of "heat machines," weather is considered as the changes of this regime, which changes are usually unavoidable in the operation of any heat machines or other machines, even those fitted with regulators.

As a rule, machines tend toward self-excited oscillation processes. Our imaginary "heat machines" in the atmosphere (and undoubtedly in the world ocean) are no exception. As long ago as 1939, Shuleykin discovered that chance thermal or dynamic perturbations in the monsoon system "ocean-atmosphere-continent" must lead to the formation of thermobaric waves in this system. In nature, these waves most frequently appear as standing waves; the last term, however, should be understood in the sense in which it is applied to waves in a rotating system, i.e., in a Coriolis force field. In this system, some nodal lines are immovably "frozen," while other nodal lines and antinodes of the temperature fluctuations rotate continuously around some pole of rotation.

The theoretically calculated picture of nodal lines and antinodes agrees well with the maps constructed by the Swedish geophysicist, Sandstrom, of temperature fluctuations in the atmosphere over Europe and the Atlantic. The natural period calculated from Shuleykin's theory agrees with the periods of temperature fluctuations actually observed during a weather change, i.e., with those natural weather periods discovered by Mul'tanovskiy. Thus, contemporary physicomathematical theory has placed solid objective bases beneath the empirical regularities discovered by Mul'tanovskiy.

As might be expected, the greatest perturbations in the monsoon currents must take place in the transitional periods; i.e., in the spring, when the summer replaces the winter monsoon, and in the fall, when the winter replaces the summer monsoon. Such increased perturbations are actually observed twice a year, causing accentuation of the standing thermobaric seiches; in spring, these are manifested as "May cold spells" or "spring cooling," and in fall, as the return of warm weather called "Indian summer." Z. I. Gavrilova's study of synoptic maps for several years showed that during the May cold spells, a unique quadripole system of antinodes, i.e., two warm antinodes and two cold antinodes, rotate over all Europe. The pole of rotation lies in the region of Penza, approximately in the same place it rested when the aggravated thermobaric seiches developed during the unusual frost in January 1940. Much work must be done to clarify the reasons for changes in the period and especially in the amplitude of fluctuations of the weather elements to perfect long-range weather forecasts. Contemporary aerology has opened a direct way to such investigations. To a considerable degree, aerology also originated in the USSR; the first good aerological instruments and methods were proposed by V. V. Kuznetsov, director of the Aerological Observatory in Pavlovsk. P. A. Molchanov used the first radiosondes. We now have the Central Aerological Observatory, directed by G. I. Golyshev, and wide potentialities for development of aerology in the maritime regions through which weather "enters the continent." We therefore expect great progress in aerology which will reveal new relationships between the ocean and the continents in their continuous powerful interaction.

Actinometric Stations

A large and well-equipped network of actinometric stations was created in the USSR by N. N. Kalitin. This network was supervised by the well-known Actinometric Institute, founded by Kalitin. The Germans destroyed this institute, but we have every reason to believe that it will be completely restored in 1948, again in the village of Sel'tsa near Leningrad, and that Kalitin will continue his work on actinometry with renewed vigor.

His contribution to the development of Soviet actinometry can be judged roughly by the following table showing the number of works published in the Soviet Union on actinometry for several continuous 5-year periods: 1913-17, 2; 1918-22, 14; 1923-27, 89; 1928-32, 133; and 1933-37, 177. As can be seen, there were no systematic studies on actinometry up to 1917 but, starting in 1918, this branch of science began to develop rapidly. In the last 30 years, over 500 works have been published, mostly by Kalitin, his students, and friends. The importance of these works to all modern branches of geophysics which depend on accurate data for the heat balance of the atmosphere and the heat balance of the sea goes without saying.

Soviet researchers have also done much in the field of theoretical actinometry, especially V. L. Kastrov, Academician V. G. Fesenkov, A. A. Dmitriyev, Ye. S. Kuznetsov, and I. I. Tikhanovskiy. Considerable actinometric equipment was developed in the USSR. The first and most reliable portable actinometer was designed by the Moscow physicist V. A. Mikhel'son and many original and valuable instruments were invented and constructed by S. I. Savinov, Kalitin, and Yu. D. Yanishevskiy. Our scientists (Berezkin, Shuleykin, and Yegorov) produced extensive actinometric studies on the ocean and were the first to make a continuous record of total radiation energy from shipboard.

Atmospheric Optics

Closely connected with actinometry are Soviet studies on atmospheric optics. Priority here belongs to the workers of the Main Geophysical Observatory, particularly to Berezkin and V. V. Sharonov. Very interesting problems of atmospheric optics in connection with astrophysics are discussed in the works of Academician V. G. Fesenkov and V. A. Ambartsumyan, Corresponding Member, Academy of Sciences USSR. In the Geophysical Institute, Academy of Sciences USSR, I. A. Khvostikov and his coworkers have intensively studied optical phenomena in the higher atmospheric layers. In particular, they produced interesting studies of night-sky luminescence and developed methods for optical sounding of the higher layers by means of powerful searchlights (see Figure 2). The work of D. N. Storozhenko in the Main Geophysical Observatory reveals interesting new trends in atmospheric optics.

V.

Since the end of the first decade of this century, atomic physics has occupied the principal place among the physical sciences. This is quite legitimate since in this field the most talented researchers have sought answers to the most basic, decisive, and important problems of science. From this standpoint, the field of geophysics has long remained in the background; the problems which fell its way were interesting, but by no means basic or all-important.

In my opinion, the time has come when, in the field of geophysics, a great number of both interesting and very important problems are being solved or are approaching solution. True, these tasks are not similar in form to the fine precision work in the field of modern quantum mechanics. In their scope and magnitude, they are more similar to the work of the natural scientists of the last century who were forced to experiment with nature directly and construct their paths on virgin soil.

/Appended figures follow:7

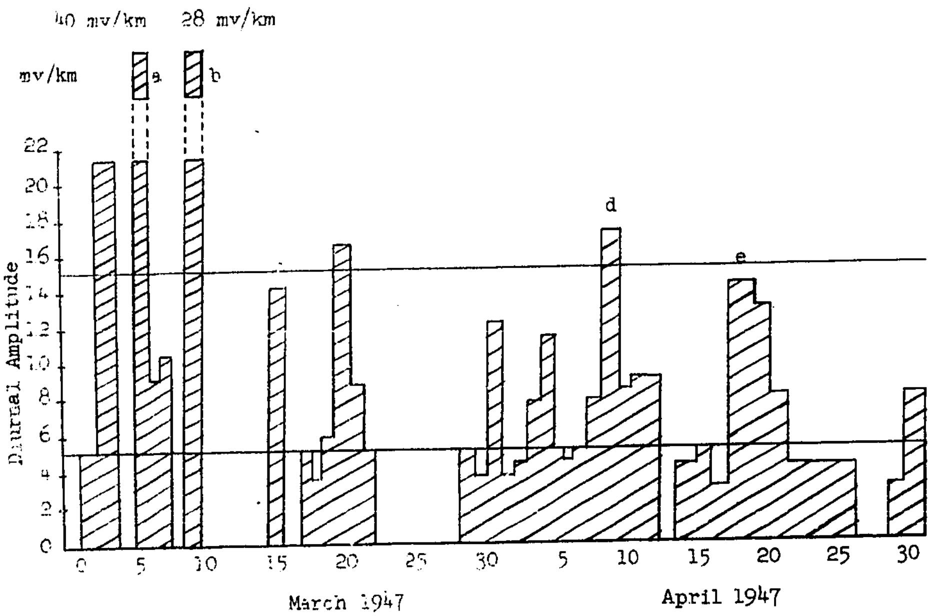

Figure 1. Connection Between Electric Mironov Currents in the Sea and Magnetic Storms for March and April 1947. a -- A very strong magnetic storm during 2 - 4 March (temporary inverse currents with amplitudes from +20 to -20 mv/km; b -- Severe magnetic storm; c -- Moderate magnetic storm; d -- Disturbance of the magnetic field; e -- Severe magnetic storm beginning suddenly on the night of 17 April and ending just as rapidly.

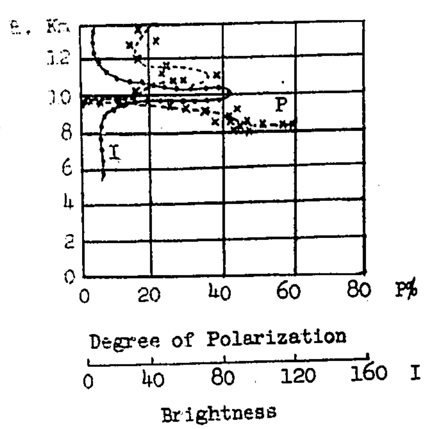

Figure 2. Dependency of Brightness and Degree of Polarization of Light on Height of Sounding (according to I. A. Khvostikov).

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